Preparation of a Polymeric Foam: An Activity Designed to Increase Teachers' Awareness of the Utility of Condensation Polymerisation

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Preparation of a Polymeric Foam: An Activity Designed to Increase Teachers' Awareness of the Utility of Condensation Polymerisation

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ABSTRACT

The new Scottish 'Curriculum for Excellence' places a greater emphasis on the societal implications of Chemistry concepts, including polymer chemistry. This has led to many Scottish secondary school teachers having little experience and background knowledge with which to satisfactorily explore the topic of polymers as they deliver the curriculum. Here we detail our development of a practical demonstration of polymer foams and its inclusion in a continuous professional development module for Scottish secondary school teachers. This demonstration has now been incorporated into chemistry classrooms across Scotland as a means of exemplifying the topic of polymers.

GRAPHICAL ABSTRACT

KEYWORDS
High School/Introductory Chemistry, Graduate Education/Research, Hands-On Learning/Manipulatives, Polymer Chemistry, Demonstrations

INTRODUCTION

Presently, in Scotland, High School educators are adapting their teaching practices to changes brought about by the introduction of the new Curriculum for Excellence (CfE). This curriculum is focused on developing learners that are prepared to enter society, and more importantly to be able to contribute effectively to it, by helping them to become successful learners, confident individuals, responsible citizens and effective contributors; these are called the four capacities.[1] These new foci necessitate a change in the specific curricular areas that are delivered in secondary science education and is neatly exemplified by both the National 5 and Higher Chemistry curricula having one of three units now entitled 'Chemistry in Society'.[2] These units deal with various areas of applied chemistry and the main emphasis is on the applications of chemistry, and how it can affect society (both positively and negatively). This change in focus towards the application of science in society is also reflected in one of the core ideas within the Next Generation Science Standards (NGSS), "The Influence of Engineering, Technology, and Science on Society and the Natural World".[3] Although the theory behind polymer chemistry was a key feature of the previous Scottish curricula, details about its application and importance to society were limited in importance. This has led to many Scottish secondary school teachers having little experience and background knowledge with which to satisfactorily explore the topic of polymers as they deliver the curriculum. This is also true in the US system, with the introduction of the NGSS.

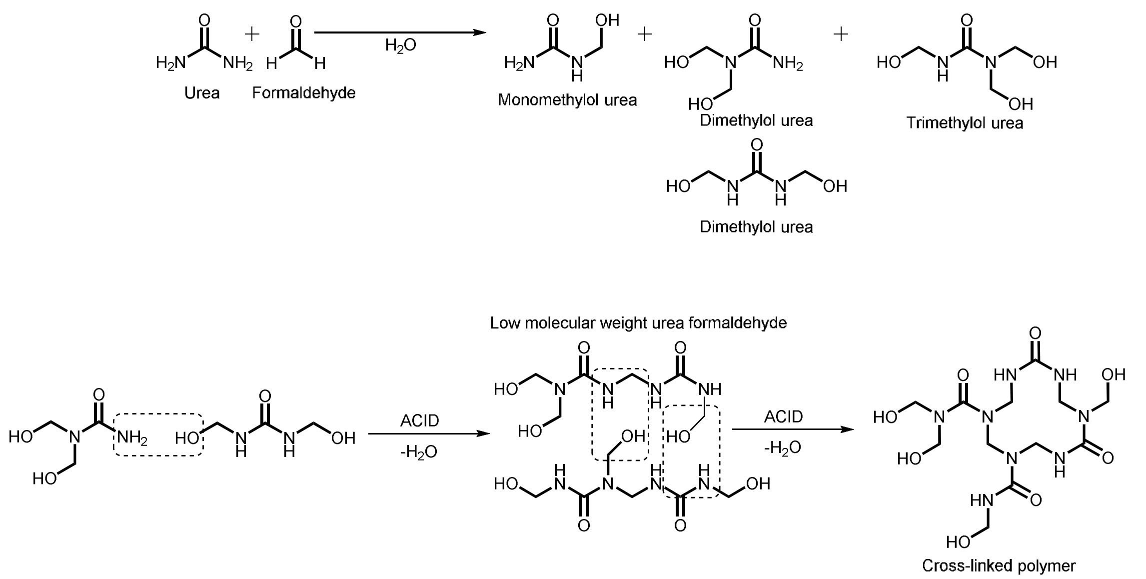
The Department of Pure and Applied Chemistry at the University of Strathclyde has recently responded to significant requests for greater Continuous Professional Development (CPD) opportunities from secondary school teachers across Scotland by developing a suite of CPD modules. These modules were designed to provide the teachers with up to date information and practical exemplification of parts of the new chemistry curricula that did not feature heavily, or at all, in the previous Scottish curricula, including the topic of polymers. We are pleased to see that recently a number of US-based counterparts are too developing polymer-based modules, aimed at generating positive impact at the secondary school level.[4,5] This demonstration presents an experiment that we developed to provide practical exemplification of the uses of polymers in society, specifically that of polymeric foams. We incorporated this experiment within our CPD module entitled, "Linking Theoretical and Practical Aspects in the National 5 Curriculum", with the aim that it would be subsequently incorporated into the participating teachers' teaching practices, and thus have wide spread reach throughout Scotland.

Polymeric foams

Polymeric foams are materials that are prepared by gas molecules becoming trapped in a solid polymer matrix. Polymeric foams are encountered routinely in daily life. Typical applications of polymeric foams include packaging materials, upholstery and insulation. Polymeric foams can be prepared from a number of chemistries and methods, but most common types routinely used include polyurethanes and polystyrene.[6] However, the preparation of polyurethane and polystyrene foams in a classroom environment, although not impossible,[7] does offer some practical challenges associated with exposure to toxic reactants, such as isocyanates.

There are other chemistries that are more appropriate for active experimentation by science pupils. One such chemistry type is urea-formaldehyde (UF),[6] which is routinely applied in the wood bonding industry for preparing wood panel boards.[8] UF polymeric foams have also been used as insulation in residential dwellings.[9] Under specific conditions and using specialist equipment it is possible to prepare UF polymeric foams.

UF foams are prepared using two main materials; urea and formaldehyde. The resulting reaction products are varied with respect to their structure and functionality. The urea-formaldehyde reaction occurs in two steps. The first step involves methylolation of urea under alkaline conditions. The degree of methylolation can be controlled to some extent in the ratio of urea to formaldehyde. The second step involves a polycondensation between the methylols to afford linear and branched polymers (scheme 1). In industrial applications the reaction between urea and formaldehyde is facilitated by the use of specialist machinery.[10] To convert the liquid urea and formaldehyde precursors into foams the machinery uses compressed air and a mixing nozzle. As the urea and formaldehyde react to form a solid the air is trapped and foam is produced.



Scheme 1: The preparation of substituted methylol ureas and their subsequent polymerization.

In the context of a practical demonstration in a classroom, the use of complicated machinery to form urea-formaldehyde foam is unfeasible. The experiment described here does not require any specialist equipment to prepare UF foam. Addition of a dilute acid to a UF solution containing sodium bicarbonate generates carbon dioxide gas, while also initiating the polycondensation of the methylolated urea. The experiment can be altered at a number of stages to highlight important aspects of chemistry and polymer chemistry such as viscosity, acid reactant (type and concentration), and the effect of surfactants/additives.

EXPERIMENT

Description of Experimental Apparatus

Standard laboratory glassware and apparatus are required for running the experiment: glass or plastic bottle as reaction vessel; magnetic stirrer bar and magnetic hot plate; solution of phosphoric acid and urea-formaldehyde (Aerolite 306); and, a surfactant (figure 1). The various components can be pre-weighed and stored prior to use by the teacher or technician.

Figure 1: Equipment and materials required for the preparation of UF foam.

Experimental – General Preparation of UF foam

To a suitable flask was added water (10 mL) and a magnetic stirrer bar. The flask was placed on a magnetic stirrer hotplate and to it was added Aerolite 306 (10 g) in small portions and mixed until homogeneous. To the Aerolite 306 solution was added sodium bicarbonate (0.5 g) and mixed until homogeneous. In a separate beaker was added 16% phosphoric acid solution (10 mL). To the beaker containing the phosphoric acid was added the surfactant, Tween 80 (0.3 g). The surfactant should be mixed with a glass rod to ensure good mixing with the phosphoric acid solution.

To the Aerolite 306 solution was rapidly added the beaker of phosphoric acid solution and surfactant. The magnetic stirrer can be switched off after 15-30 seconds, upon formation of the polymer foam.

Tips for a successful experiment – The various chemicals and solutions used can be pre-weighed prior to being provided to the participants. The pre-weighing is especially helpful when there are a large number of participants and the availability of balances is limited. The Aerolite 306 may agglomerate if added too quickly to the water, if this is the case the clumps should be broken up with a spatula/glass rod to allow for a homogeneous solution of urea-formaldehyde to be prepared. Before the foam begins to react and harden the magnetic stirrer used to mix the reactants can be extracted quickly by use of a magnetic retriever. The foam reaction vessel should be placed on top of some paper towels, to facilitate a simple clean up, in cases where the foam reaction escapes the reaction vessel (figure 2).

Figure 2: A paper towel used to facilitate clean up.

The experimental procedure sheet can be found as supporting information.

Experimental – Variations on Foam Preparation

It is possible to alter the standard experimental to investigate ancillary areas associated with polymer chemistry.

Viscosity - the concept of viscosity can be explained by investigation of various concentrations of Aerolite 306. At concentrations greater than 50 % (w/v) the solution will become difficult to stir by use of a magnetic stirrer. It is also possible to decrease the concentration of Aerolite 306 to show that it is possible to decrease the viscosity of the system, but at the expense of the volume and quality of foam prepared.

Acid reactant - Phosphoric acid (16 %) is used in the standard experimental. It is possible to use alternative concentrations to show what effect this has on the rate of reaction and the quantity and quality of foam produced. It is also possible to investigate other acidic solutions, such as formic acid, and observe their effects on the urea-formaldehyde reaction.

Surfactants and additives – The omission of either the sodium bicarbonate or the surfactant will have significant effects on the outcome of the reaction. Failure to add the sodium bicarbonate will provide a solid material as opposed to foam. It is also possible to vary the concentration of sodium bicarbonate used to obtain foam with varied density. If the sodium bicarbonate is added, but the surfactant is omitted, the cells of the foam will not be stabilized, whilst the reaction between urea and formaldehyde proceeds to completion. Different surfactants, other than Tween 80, could also be investigated.

Hazards and hazard mitigation

The UF used during the experiment is purchased in powder form. The powder UF is converted to a solution and used as such during the activity. UF may contain residual formaldehyde. To mitigate any potential risk of exposure to formaldehyde the UF should be pre-weighed in a fume cupboard and bottled prior to use by the activity participants.

The phosphoric acid is corrosive and an irritant. The dilute solution should be prepared by the activity coordinator and given to the activity participants pre-weighed so as to prevent exposure.

Given the hazards associated with UF and phosphoric acid the participants are required to wear safety glasses and gloves during the activity.

The reaction generates carbon dioxide when the phosphoric acid is added to the urea-formaldehyde solution. The reaction vessel should not be capped as the gas is generated, as this capping may result in pressurization of the reaction vessel. The reaction vessel should be left to stand uncapped for a minimum of 24 hours before capping to ensure the risk of pressurization is minimized.

RESULTS AND DISCUSSION

Experiment Implementation

The experiment can be completed in 10-15 minutes if using only one set of conditions. During the running of the CPD module, we had teachers working in pairs to simulate the experience that we intended to be given to students who would eventually carry out the experiment.

The variations to the experimental (viscosity, acid reactant and the presence of additives) of the foam experiment allow for investigation into other areas of scientific interest beyond polymerisation.

The viscosity and concentration of the UF solution has significant effects on the quality of foam produced. Students will find that concentrated solutions of UF will be difficult to disperse and will not be suitable to be converted to foam. If the students make the UF solution dilute they will recognize the low viscosity, but at the expense of the foam quantity and quality produced.

Moving from phosphoric acid to formic acid solution (30-60 %) will result in a much reduced rate of foam reaction. The absence of key components such as the surfactant or sodium bicarbonate will affect the generation and stabilization of the foam. For example, the importance of sodium bicarbonate can be demonstrated by comparing the density of the foam prepared with sodium bicarbonate (top, figure 3) against material prepared without sodium bicarbonate by placing both in a beaker of water (bottom, figure 3).

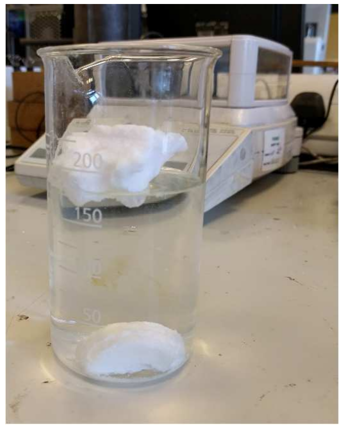


Figure 3: Comparing the density of foam prepared with sodium bicarbonate (top) against material prepared without sodium bicarbonate (bottom) by placing in a beaker of water.

Developing Polymer Knowledge in Secondary Teachers and Students

This experiment was carried out by 30 secondary school teachers during a CPD module run in 2016, and by a further 16 teachers in a repeat presentation of the module in 2017. We asked the teachers to assess the usefulness of this practical through completion of a short questionnaire comprised of a 5-point Likert-like response item (of no use; of very little use; of some use; useful; very useful) and the opportunity to provide free text response. 93% (43 out of 46) of the teachers responded that they found the experiment either useful or very useful, with 87% (40 out of 46) responding that they found the experiment to be very useful. Further encouraging comments were seen in the free text responses where the most frequent comments related to the teachers' desires to carry out the experiment in the classes e.g. "I'm excited to try this out with my class when we get to the polymers topic". Although this experiment was delivered to teachers during one of our CPD modules, we did this in the hope that they would incorporate it into their delivery of the curriculum in their classrooms. Our ultimate goal was to enrich the experience school students have of the polymer curricular area. Thus, rather than measuring the success of the experiment through gauging teachers perceived usefulness of the experiment, we believe that a better measure of success can be determined through measuring the number of students that have experienced this activity as a result of our training of their classroom teachers. To this end, we surveyed all participants of the CPD modules 3 months after their delivery and, pleasingly, our feedback has indicated that at least 1000 secondary school students across Scotland have now carried out this experiment.

ASSOCIATED CONTENT

Supporting Information

The experimental procedure sheet used during the CPD module, and that to be used in classes with students. A risk assessment sheet for the experiment.

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